# <u>Design  Development and Analysis of a Humanoid Robot</u>

Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor & Masters (Dual) of Technology in Mechanical Engineering

By

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## CERTIFICATE

This is to affirm that the work in this proposition entitled "Design Development and Analysis of Humanoid Robot" by Navin Kumar, has been done under my supervision in halfway satisfaction of the necessities for the level of Bachelor & Masters (Dual) of Technology in Mechanical Engineering throughout session 2014 – 2015 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my learning, this work has not been submitted to any other College/Institute for the honor of any degree or recognition.


Dr. Dayal R. Parhi

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National Institute of Technology Rourkela

# Acknowledgement

We put on record and warmly recognize the consistent support, precious supervision, convenient proposals and motivated direction offered by our aide Prof. Dayal R. Parhi, Department of Mechanical Engineering, National Institute of Technology, Rourkela, in bringing this report to a fruitful finishing. We see ourselves as greatly blessed to have had the open door to work under the direction of such a learned, powerful and liberal identity. We are additionally grateful to Prof S.S. Mohapatra, Head of Department, Department of Mechanical Engineering; National Institute of Technology Rourkela; for his consistent backing and consolation.

At long last, we stretch out our genuine on account of Mahesh sir for his backing all around the undertaking work.

Navin Kumar

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***Abstract—***

**Humanoid robots are those resembling their motion and functioning similar to human beings, having capabilities of doing day to day activities similar to man and replace him in every possible way. These activities vary from daily activities such as walking, standing, and bowing, to staircase climbing, running, and kneeling. The current research integrates multiple technologies and methodologies within a system such as 3D printing, Inverse Kinematic programming, Power electronics, Control system, Learning algorithms, Mechanical Design, Human-computer interaction, software tools for collaborative projects. A detailed mechanical design procedure has been carried out in CAD along with its structural analysis in FEA. Followed by Kinematic and Dynamic analysis of the system considering suitable physical properties in V-rep.**

**Keywords - Humanoid Robot, 3D printing, Inverse Kinematics**

# Chapter 1

## Introduction

# Introduction

Humanoid robot is another class of mobile robots which resembles human behavior in appearance and also in motion. Lately robots have been designed which are replica of human face and show expressions similar to human beings, whereas some are designed for user friendly interactions or use to perform delicate tasks impossible to carry out by man. If these robots resemble in terms of material texture or physical appearance then these may be called as Android robots. Currently the robots developed are costly very costly and undergo a sophisticated process for manufacturing. For example robots like Honda Asimov & Fujitsu HOAP fall under the category of expensive designed by well-funded companies and research labs. Due to advancement in material science, cheap manufacturing of motors & batteries, small sensor systems and increase in processing capabilities of embedded systems led to a new era of tiny affordable robots such as Hansa Ram, Manus, Tao-Pie-Pie and many more are being developed by hobbyists all across the world.

Another reason for the increase in research in this field is due to many high end profile and complicated competitions such as RoboCup and FIRA coincided their interest in the international world. Robotic soccer was chosen a challenge that requires artificial intelligence and knowledge of robotics for the academic fields. These competitions need higher level of intelligence for defensive & offensive strategy, path planning, motion planning & control, image processing etc which are dynamic and need to be processed in real time environment with multi sensors and opponents to achieve its objective and compare the result to similar real life examples and events. Adaptability, flexibility & robustness are vital for the robot to perform for longer durations in sophisticated and variable environment.

Goals have been set for the future that in 2050, a team of humanoid robots will compete with the winner of the football in Soccer. Darpa also is planning to create contest related to humanoid robots which can perform tasks as complicated as humans can do.  Many innovations and technological advancement can been seen developed by research labs and universities.

## History of Humanoid Robots

Early robots

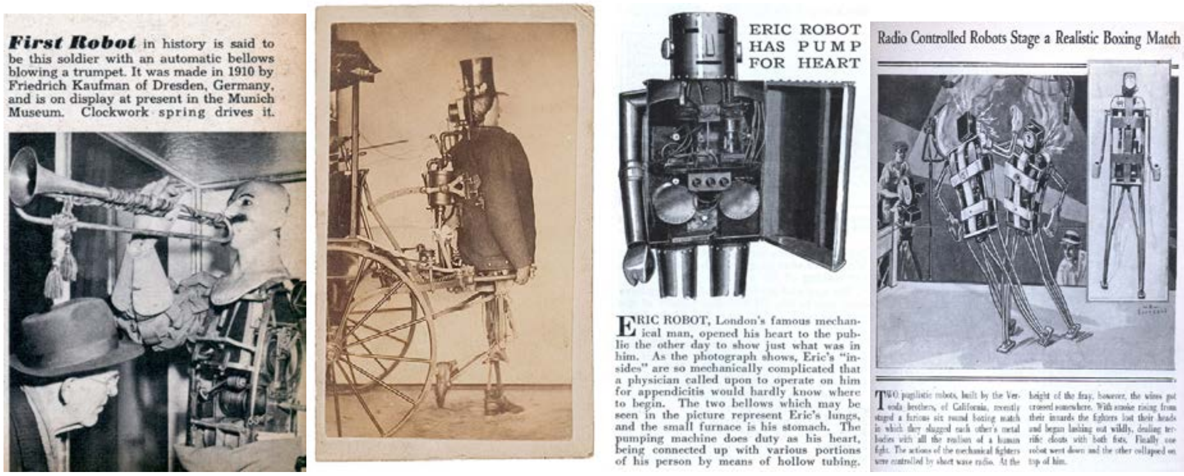



Fig 1a, 1b, 1c, 1d. Showing articles related to Early Robots. [1]

Mid Robots


Fig 2a, 2b, 2c, 2d. Showing articles related to Mid Robots. [1]

Latest Robots

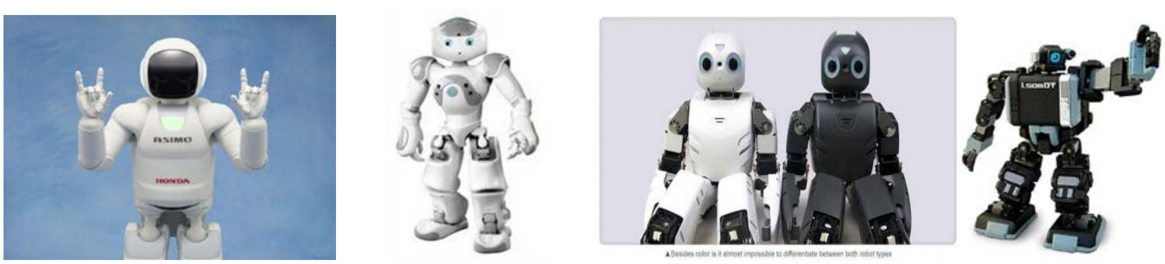



Fig 3a, 3b, 3c, 3d. Showing images of latest robots. [1]

# Chapter 2

# Literature Review

# Literature Review

## Motivation

During my childhood days I watched a movie named as "RoboCop" in which a semi humanoid robot protects people danger. Since then I always wanted to develop a robot of my own and contributing to the society of Robotics and make this world a better place. But most people think of humanoids as a machine of destruction influenced by the movie "The Terminator – I, II, III" in which a machine is sent from the future to kill people and save some of them. There may be a time in future when robots will turn into destructive machines but as of today the robots help us in every day to day activity and we don't even realize the importance. Yet Artificial Intelligence is on its way to change the way of control of machines. With the rate of development of algorithms and more powerful computers we will soon be able to observe robots in day to day lives.

Considering the situation, it should be our duty to develop an effective and advanced robot that can easily be built and get acquinted in to our lives. Still development of complete humanoid alone is a challenging task but nothing is impossible. But the major challenge is control of walking motors and stabilizing the robot on its own.

Biped robots are a part of humanoid robots where the focus is primarily given on the walking motion analysis of the robot. Many several such attempts have been made since 1993 to develop a smooth uniform walking characteristic replicating human way of walking. [2-5] J. Yamaguchi, A. Takanishi And I. Kato presented their research on Biped motion in which three axis moment was compensated in IEEE in Japan.

But around 1973 Waseda University designed the Wabot (a biped robot) which is known as first well known robot falling into the category of humanoid robots.[6-10]. Since then the university has been engaged into developing the family of robots and have achieved mile stones which can only be accomplished by true dedication.

A well known humanoid robot till now is ASIMO Honda which has been developed by the company Honda and was released in 2000. But Honda has developed various prototypes before the ASIMO robot and many of them failures. It took them a decade to actually develop this wonderfull robot which has unimaginable specifications. In 1996they revealed their robot which had the self regulating feature and was known for first of its kind. Consequetive improvement and developemnet made ASIMO the best of all the robots and the humanoid robots. This robot can perform tasks like running, climbing and a lot more. [11 - 12].

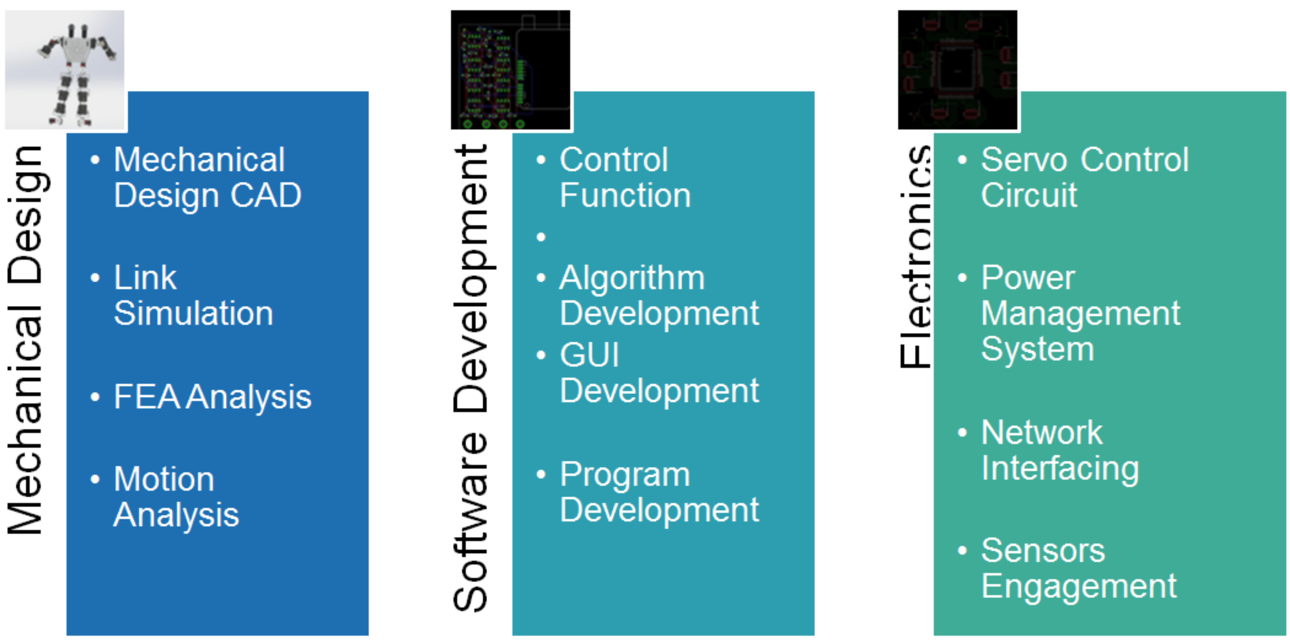
# Chapter 3

# Design Methodology

## Design Methodology

### Overview

The whole mechanical design was done by using a 3D CAD software, SolidWorks 2013. The following design has been inspired by Poppy Beta (Flowers). The body of Poppy is mainly made of ABS plastic in order to realize antithetical concepts; light weight, high stiffness and wide movable range. Each actuator system of joint consists of a DC High torque servo motors. These motors comprises of sequential gears and heavy load carrying capability with large reduction ratio attached with a potentiometer to obtain the desired position and feedback. Properties of joints like maximum torque and rotating angular velocity are acquired based on data of software simulations. Newton-Euler's Method can be used to simulate the estimated mass distribution and the behavior of the robot under static and dynamic conditions. A series of the simulations were carried out for the determination of the joint specification. The details are described as follow.



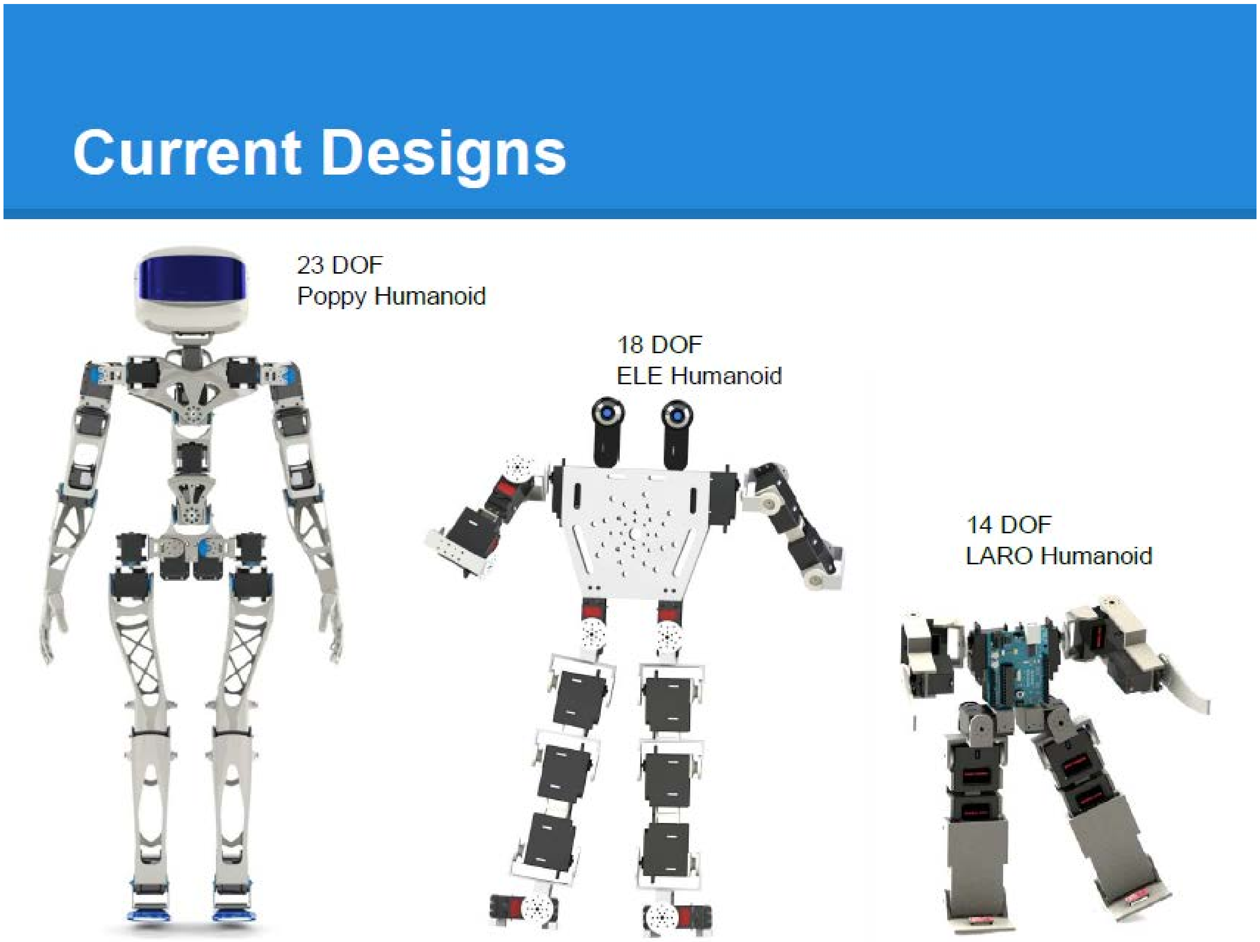



Fig 4. Comparison of the designed robots through CAD

| Robot/ Specs | DOF | Height | Weight | Motors | Cost | Fabrication | Power Supply |
|---|---|---|---|---|---|---|---|
| Poppy Humanoid | 23 | 810 mm | 3 Kgs approx | Dynamixel Motors | Rs 4,00,000/- | 3D Printing | External 12vl |
| ELE Humanoid | 18 | 500 mm | 1.5 kgs | Single Shaft High Torque | Rs 1,00,000/- | 3D Printing | Optional 6v |
| LARO Humanoid | 14 | 300 mm | 1kg | Dual Shaft Medium Torque | Rs 80,000/- | 3D Printing | Onboard 7.5v |

Table 1. Comparison of features of the robot.

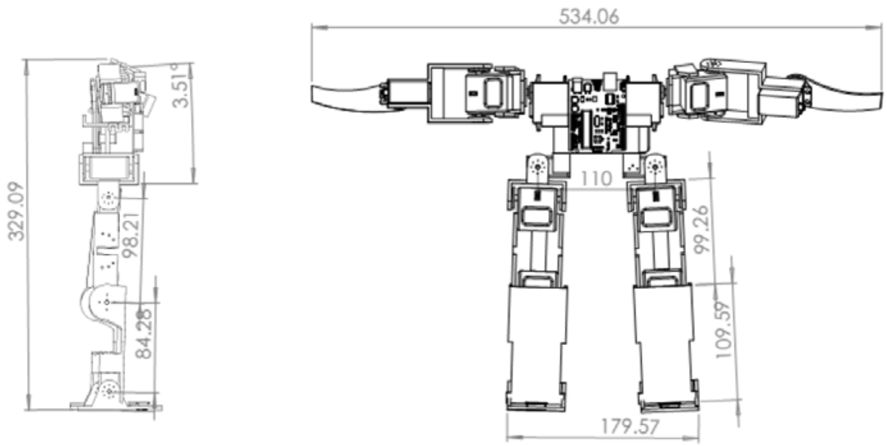



Fig 5. Drafted view of Laro Humanoid

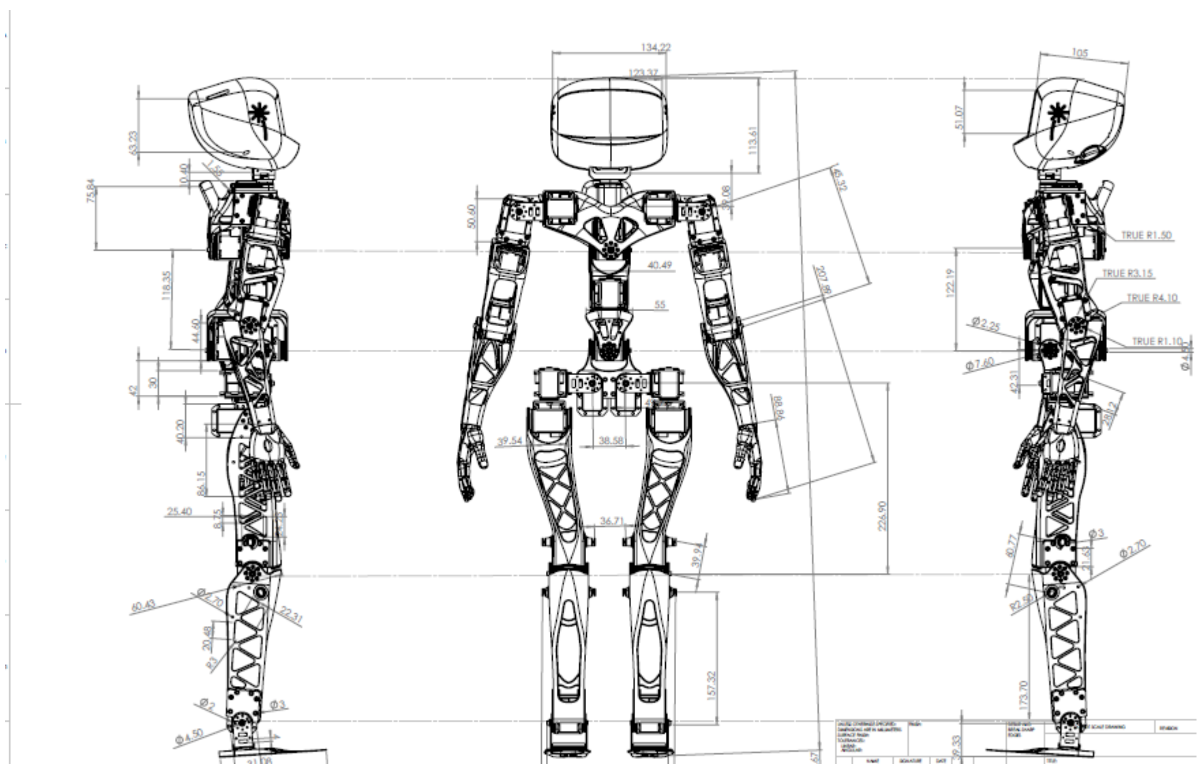


Fig 6. Drfated view of Poppy Beta developed by Flowers.

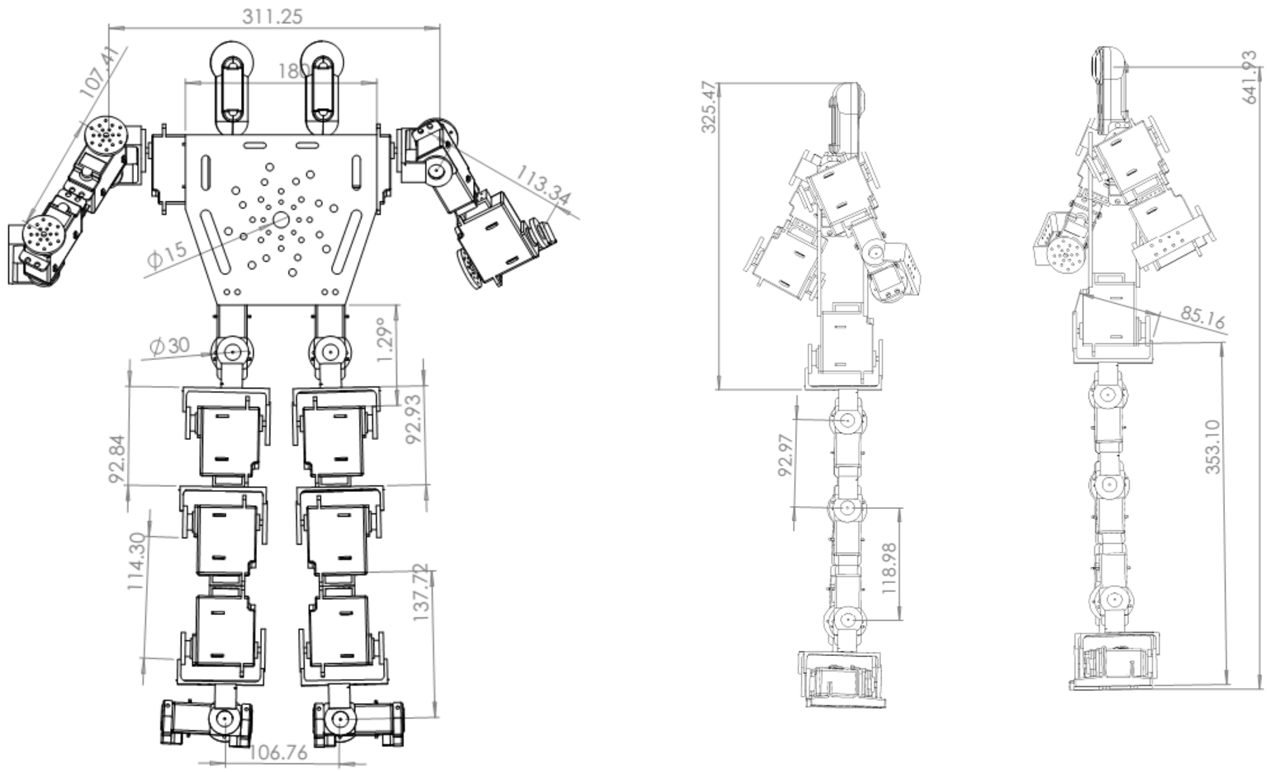
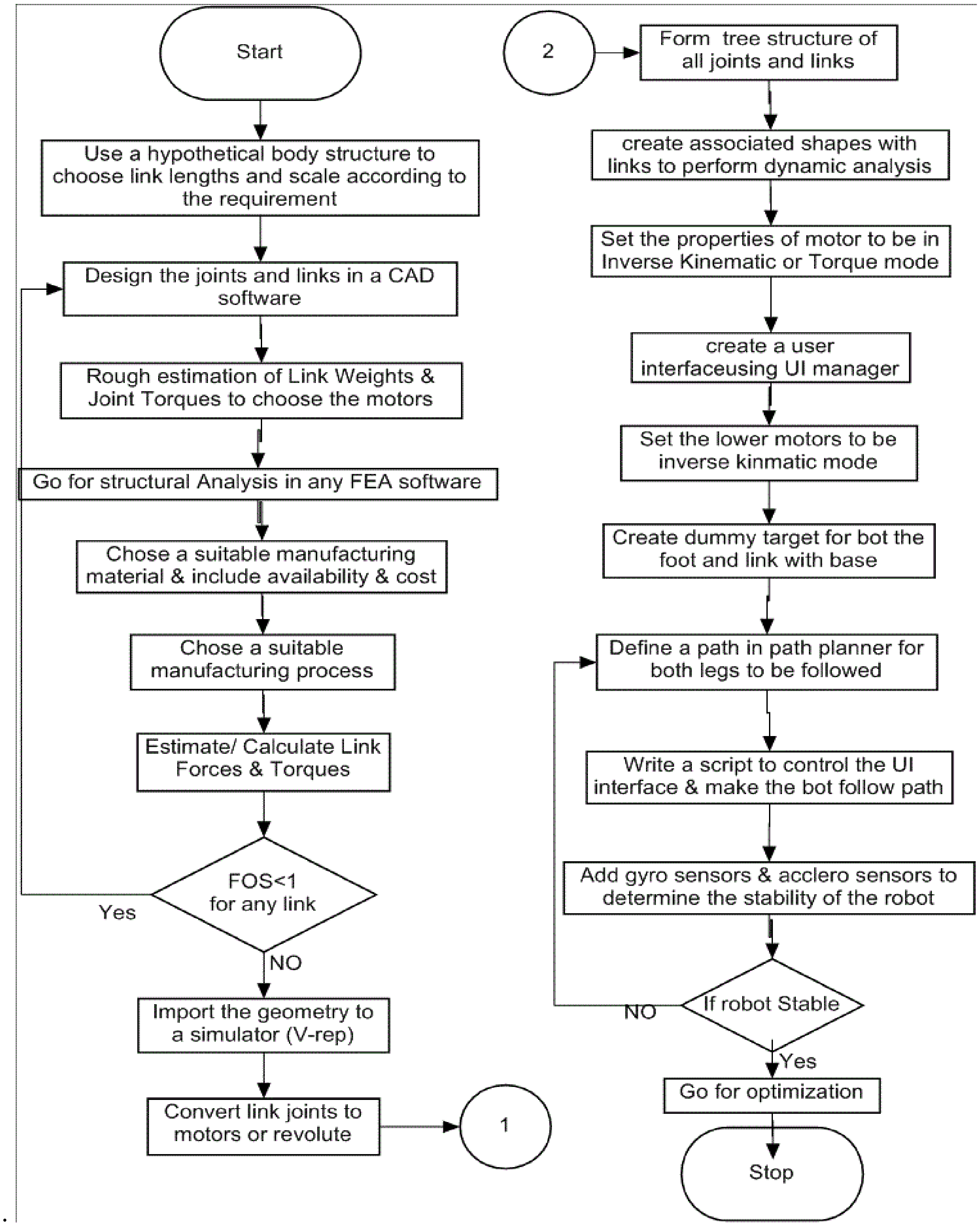



Fig 7. Drafted view of ELE humanoid


Start
Use a hypothetical body structure to choose link lengths and scale according to the requirement
Design the joints and links in a CAD software
Rough estimation of Link Weights & Joint Torques to choose the motors
Go for structural Analysis in any FEA software
Chose a suitable manufacturing material & include availability & cost
Chose a suitable manufacturing process
Estimate/ Calculate Link Forces & Torques
FOS<1 for any link
Yes
NO
Import the geometry to a simulator (V-rep)
Convert link joints to motors or revolute
1
2
Form tree structure of all joints and links
create associated shapes with links to perform dynamic analysis
Set the properties of motor to be in Inverse Kinematic or Torque mode
create a user interfaceusing UI manager
Set the lower motors to be inverse kinmatic mode
Create dummy target for bot the foot and link with base
Define a path in path planner for both legs to be followed
Write a script to control the UI interface & make the bot follow path
Add gyro sensors & acclero sensors to determine the stability of the robot
If robot Stable
NO
Yes
Go for optimization
Stop

# Chapter 4

# FEA Analysis of Robotics Parts

Finite Element Analysis helps to determine the part strength of the model in various conditions and geometries. Since the approach is completely computational the cost of analysis is very minimum and the results obtained are in due time.


Fig 8. Design and analysis of limbs of humanoid parts.

The geometry can be designed in any CAD software and imported in Ansys 14.0 where meshing can be applied to divide the structure into sub parts using 8 nodes or 16 nodes method. Refinement of mesh can be applied to the areas where the geometry gets complicated or the thickness of some boundary is too less. The material library needs to be imported or created from the data available online through material specific websites. The table shows some physical properties of ABS plastic which will be used to develop the parts using 3D printing technique. ABS has Elastic Modulus of 2000 N/mm^2 with poisson's ratio of 0.395 which is comparable to most of the plastics generally available. The mass density of ABS is 1020 Kg/m^3 with shear modulus of 318.9 N/mm^2 with tensile strength of 30N/mm^2. The thermal conductivity and specific heat are of no use in this project so they can be neglected. The rest parameters suit the needs required.

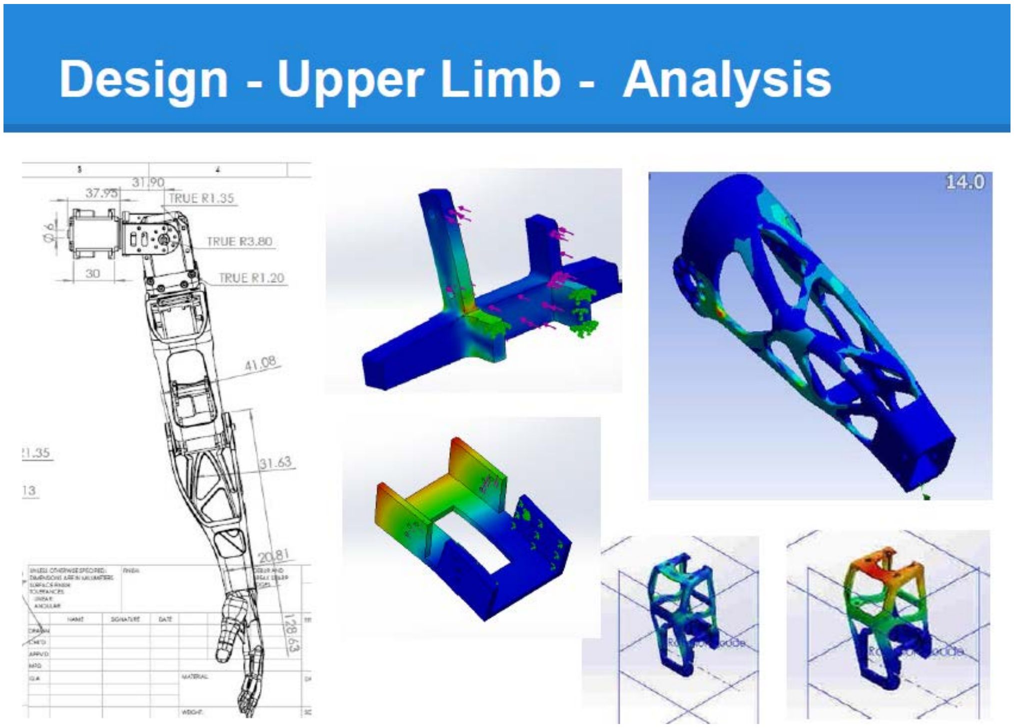



Fig 9. Design and analysis of upper body parts of humanoid robot.

The boundary conditions can be applied as pressure, force, fixed support, frictional support, bearing support, Elastic support along with temperature points which are not necessary in this project. Advanced features contains Torque, gravity, centrifugal force, bearing load, distributed load, Remote load and various other conditions are also available which can be used to analyze complex situations.

| Property | Value | Units |
|---|---|---|
| Elastic Modulus | 2000 | N/mm^2 |
| Poisson's Ratio | 0.394 | N/A |
| Shear Modulus | 318.9 | N/mm^2 |
| Mass Density | 1020 | kg/m^3 |
| Tensile Strength | 30 | N/mm^2 |
| Compressive Strength | | N/mm^2 |
| Yield Strength | | N/mm^2 |
| Thermal Expansion Coefficient | | /K |
| Thermal Conductivity | 0.2256 | W/(m·K) |
| Specific Heat | 1386 | J/(kg·K) |
| Material Damping Ratio | | N/A |

Table 2. Properties of ABS Plastic

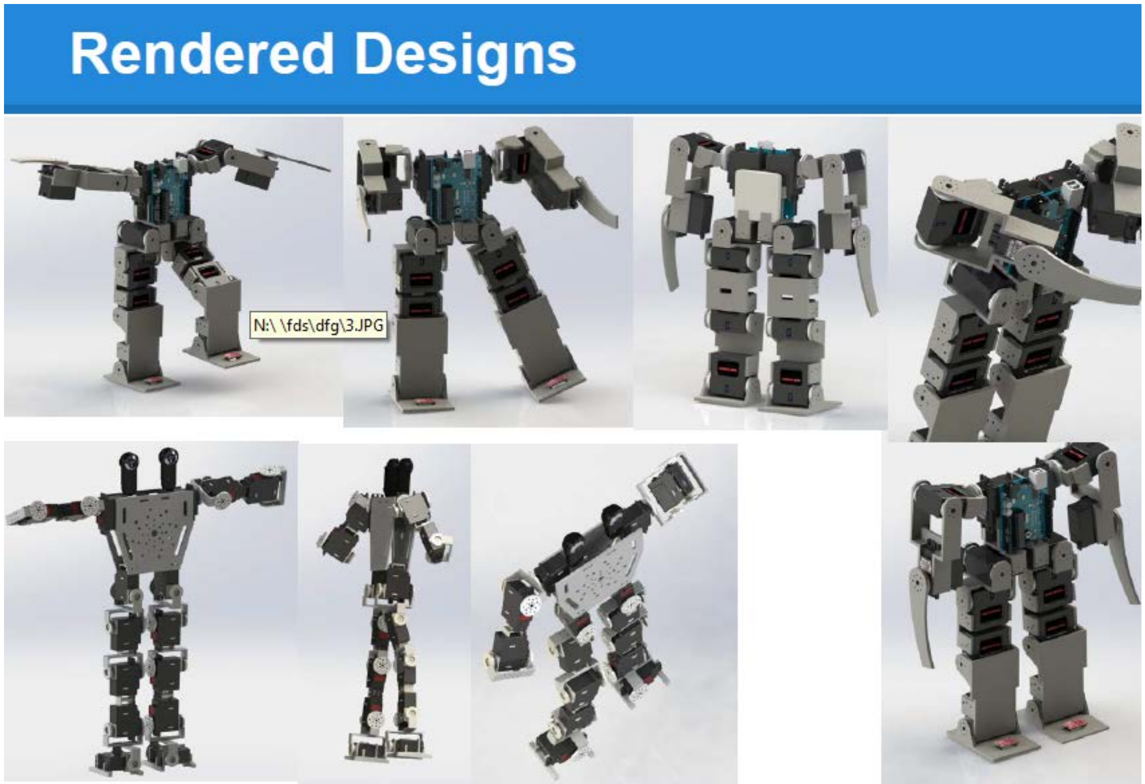



Fig 10. Rendered view of the robots

# Chapter 5

# Electronics

The main control part is done by a microcontroller in the path controlling of a robot. Since the complexity of the system is high a more computer is needed to perform the task. The networking gets complicated and a power management system is needed to provide current to all the motors. A schematic diagram is shown in the pictures below to represent all the systems and sub systems embedded in the robot.

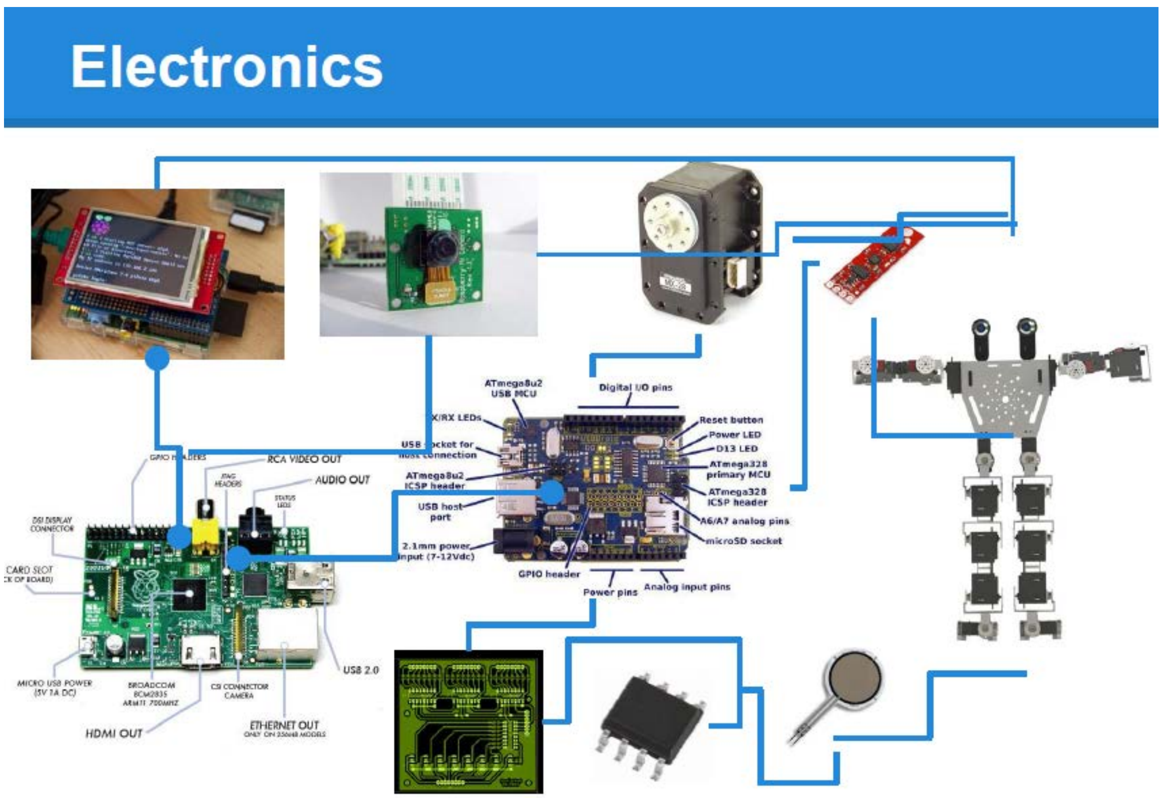



Fig 11. Visual Schematics of the electronic components

The main computer used can be as powerful as Raspberry pi or equivalent with processing power of 700 Mhz. Since the operating is linux based so there is no issue in licensing and hence open source projects can be carried out. Another microcontroller is connected in series to interface the sensors. Since Pi doesn’t have any onboard ADC, this microcontroller is needed.

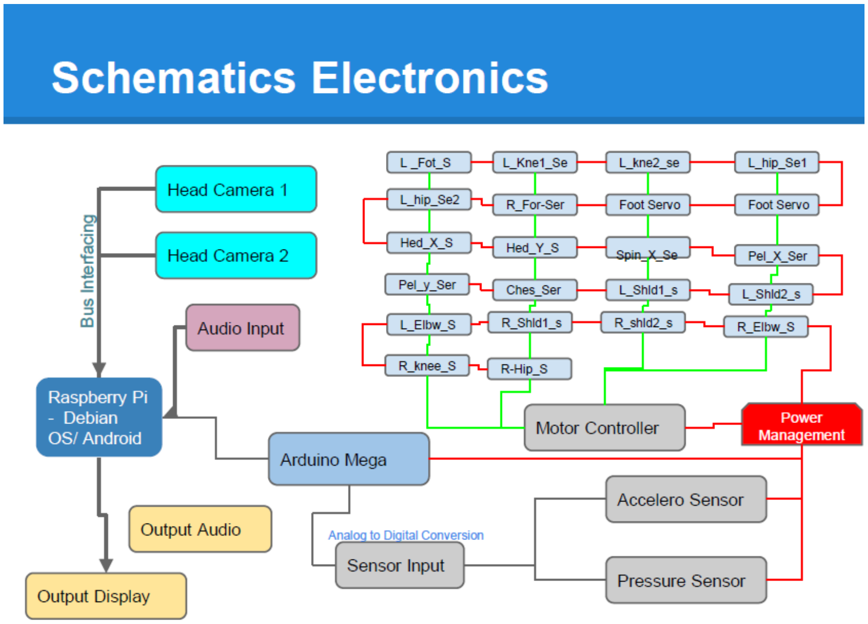
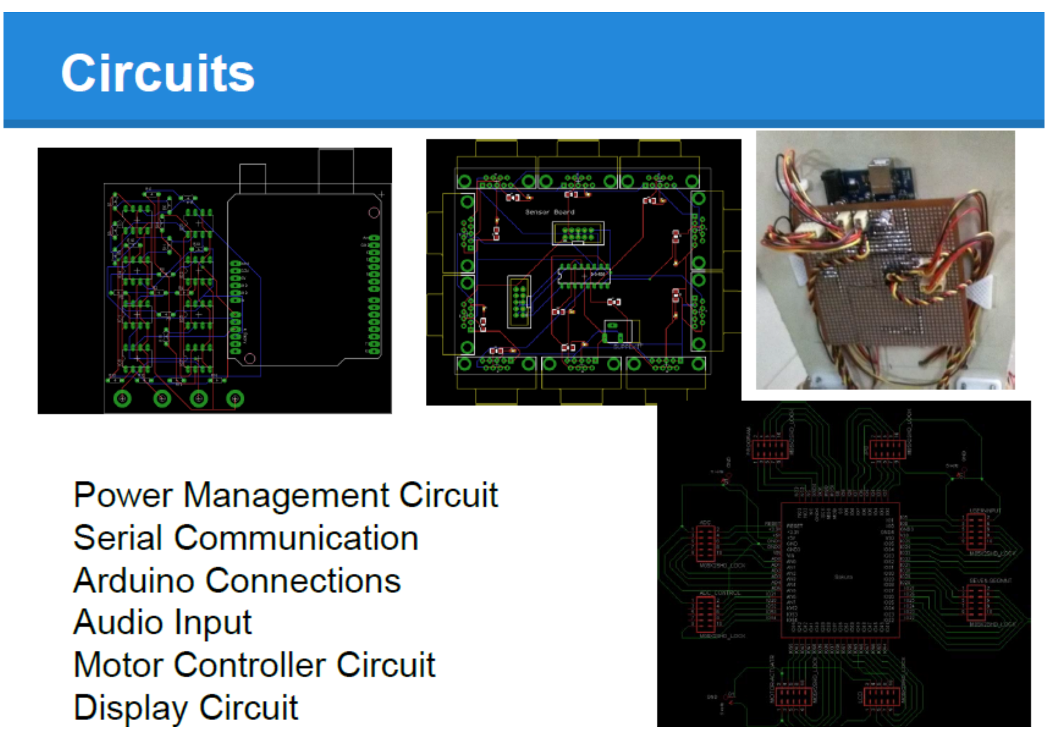



Fig 12. Schematics of electronic connections

There is also a feature of embedding a camera onboard for visual based task through image processing. Since the size of the Pi is small it can be easily placed on board. Arduino mega is connected in parallel which is connected to all the servo motors. The motors need a pwm to move to a specific angle and maintain the required torque. The display can be a LCD connected to Pi which delivers great results.



# Chapter 6

# V-rep Simulation

Design Parts and their specifications

Material - PLA, Elastic Modulus - 1650x10^6 N/m^2, Poisson - 0.394, Yield Stress - 3189x10^5 N/m^2

| Part | Material | Mass | Volume | Surface Area | CG (X) | CG (Y) | CG (Z) | Length | Width | Height | MOI (Ixx) | MOI (Iyy) | MOI (Izz) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hip | Polyamide | 25gm | 32446.86 mm^3 | 18569.06 mm^2 | 0.0 mm | 2.47mm | 1.29mm | 80.64 mm | 54.63 mm | 45.84 mm | 9915.28 | 20776.98 | 931.21 |
| Chest | Polyamide | 117.56 gm | 1269406.70 mm^2 | 80704.90 mm^2 | 0.01 mm | 43.32 mm | 43.69 mm | 156.60 mm | 60.58 mm | 87.63 mm | 581698.52 | 50.53 | 456178.18 |
| Spine | Polyamide | 18.12 gm | 19478.65 | 15207.55 | 0.00 mm | 2.81 mm | 6.70 mm | 63.54 mm | 48.97 mm | 48.32 mm | 11782.31 | 10116.83 | 13659.63 |
| Thigh | Polyamide | 52.37 gm | 56312.57 | 41376.49 | -2.47 mm | 90.67 mm | -9.82 mm | 180.84 mm | 52.01 mm | 53.56 mm | 607197.41 | 47982.83 | 597464.02 |
| Knee | Polyamide | 42.85 gm | 46071.36 | 37562.73 | -5.54 | 107.61 | -0.00 | 203.54 mm | 41.96 mm | 43.65 mm | -646694.61 | 28492.94 | 648517.07 |
| Foot | Polyamide | 17.68 gm | 19013.75 | 9410.51 | 6.07 mm | 3.78 mm | -40.63 mm | 125.53 mm | 70.56 mm | 64.32 mm | 39396.44 | 42583.41 | 3882.32 |
| Arm Design | Polyamide | 17.60 gm | 17599.31 | 17386.99 | -0.00 mm | 56.34 mm | 1.62 mm | 80.56 mm | 38.53 mm | 41.80 mm | 79307.75 | 10802.27 | 77592.03 |
| Hand Design | Polyamide | 20.54 gm | 22085.32 | 18892.55 | 4.44 mm | -49.38 mm | -10.18 mm | 128.63 mm | 36.40 mm | 40.53 mm | 95446.73 | -8232.76 | 94945.73 |
| Head Design | Polyamide | 134.29 gm | 144396.92 | 134244.05 | 1.18 mm | 83.90 mm | -13.87 mm | 119.05 mm | 93.54 mm | 108.70 mm | 1275233.50 | 409155.88 | 1286469.25 |

## Simulation in V-rep

At present, all evaluations of the robot have taken place in a ROS based dynamic simulator named as V-Rep simulator, developed by COPPELIA ROBOTICS. V-Rep is an object-oriented, open source code platform that provides full static & dynamic simulation for tree-structured robots where kinematics is carried out. Moreover the setup can be modified using various algorithms to simulate both fixed and mobile bases. The library of V-rep has been developed using recursive algorithms also with kinematic inversion  to perform dynamic calculations, and eventually provide graphical display of the  entire robotic setup in an Open-GL graphics library. ROS package has been used as a core by the simulator along with driving control of DC as well as servo motor, different sensors and one to one serial protocol as well. D-H kinematic analysis is also used to perform various simulation in inverse as well as forward kinematics. The solidworks part design is imported into the viewer in the form of Stl extension and also facility is available to develop primitive shapes in custom shapes. The developed simulator uses an integration step time size of 500µs and updation is needed every 5ms of  running simulated time

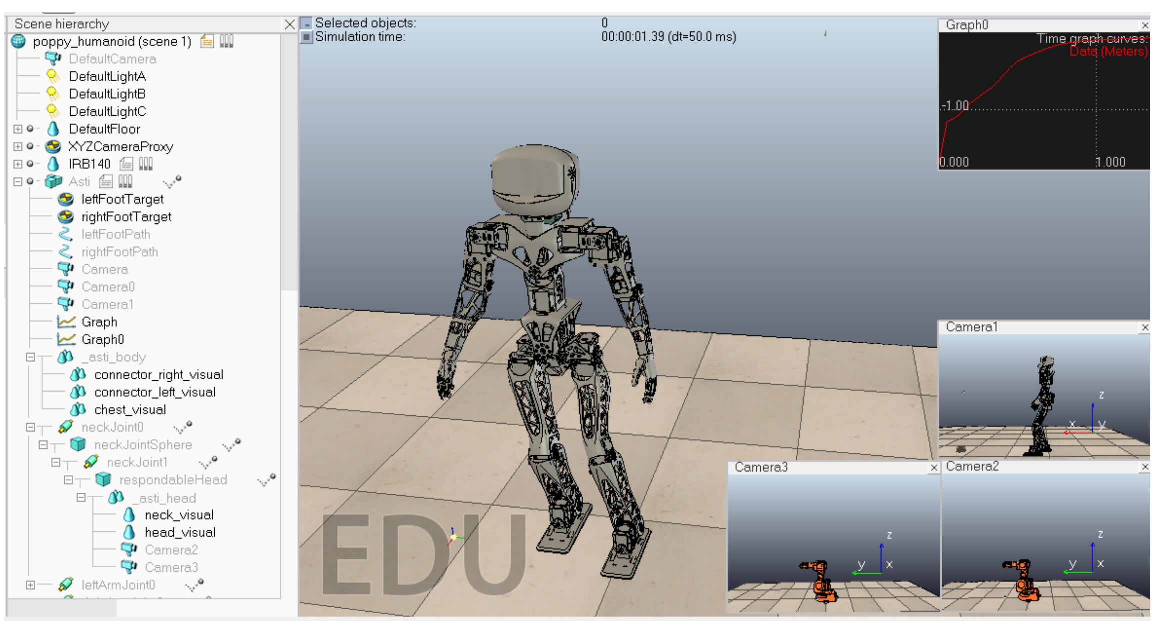



Fig 13. Simulation in V-rep

Script

```
if (simGetScriptExecutionCount()==0) then
    Humnaoid=simGetObjectHandle("Humnaoid")
    foot_l=simGetObjectHandle("foot_left")
    rightt-foot=simGetObjectHandle("foot_right")
    pathlength=simGetObjectHandle("leftFootPath")
    ppath=simGetObjectHandle("rightFootPath")
    pathlengthLength=simGetPathLength(pathlength)
    ppathLength=simGetPathLength(ppath)
    ui=simGetUIHandle("HumnaoidUserInterface")
    simSetUIButtonLabel(ui,0,simGetObjectName(Humnaoid).." user interface")
    dist=0
    correction=0.0305

    Value_minimum={0,
            0,
            -math.pi/8,
            -math.pi/2,
            0,
            -math.pi/2,
            -math.pi/2,
            0,
            -math.pi/2}
    value_range={   2,
                0.8,
                math.pi,
                math.pi/4,
                math.pi/2,
                math.pi/2,
                math.pi/2,
                math.pi/2,
                math.pi/2,
                math.pi/2}
    uiSliderIDs={3,4,5,6,7,8,9,10,11,12}
```

```
    stepIse=1
    velocty=0.4
    neckJoints={simGetObjectHandle("neckJoint0"),simGetObjectHandle("neckJoint1")}
    leftArmJoints={simGetObjectHandle("leftArmJoint0"),simGetObjectHandle("leftArmJoint1"),simGetObjectHandle("leftArmJoint2")}
    rightArmJoints={simGetObjectHandle("rightArmJoint0"),simGetObjectHandle("rightArmJoint1"),simGetObjectHandle("rightArmJoint


    simSetUISlider(ui,uiSliderIDs[1],(stepIse-Value_minimum[1])*1000/value_range[1])
    simSetUISlider(ui,uiSliderIDs[2],(velocty-Value_minimum[2])*1000/value_range[2])
    simSetUISlider(ui,uiSliderIDs[3],(simGetJointPosition(neckJoints[1])-Value_minimum[3])*1000/value_range[3])
    simSetUISlider(ui,uiSliderIDs[4],(simGetJointPosition(neckJoints[2])-Value_minimum[4])*1000/value_range[4])
    simSetUISlider(ui,uiSliderIDs[5],(simGetJointPosition(leftArmJoints[1])-Value_minimum[5])*1000/value_range[5])
    simSetUISlider(ui,uiSliderIDs[6],(simGetJointPosition(leftArmJoints[2])-Value_minimum[6])*1000/value_range[6])
    simSetUISlider(ui,uiSliderIDs[7],(simGetJointPosition(leftArmJoints[3])-Value_minimum[7])*1000/value_range[7])
    simSetUISlider(ui,uiSliderIDs[8],(simGetJointPosition(rightArmJoints[1])-Value_minimum[8])*1000/value_range[8])
    simSetUISlider(ui,uiSliderIDs[9],(simGetJointPosition(rightArmJoints[2])-Value_minimum[9])*1000/value_range[9])
    simSetUISlider(ui,uiSliderIDs[10],(simGetJointPosition(rightArmJoints[3])-Value_minimum[10])*1000/value_range[10])
nd

imHandleChildScript(sim_handle_all_except_explicit)


tepIse=Value_minimum[1]+simGetUISlider(ui,uiSliderIDs[1])*value_range[1]/1000
elocty=Value_minimum[2]+simGetUISlider(ui,uiSliderIDs[2])*value_range[2]/1000
imSetJointTargetPosition(neckJoints[1],Value_minimum[3]+simGetUISlider(ui,uiSliderIDs[3])*value_range[3]/1000)
imSetJointTargetPosition(neckJoints[2],Value_minimum[4]+simGetUISlider(ui,uiSliderIDs[4])*value_range[4]/1000)
imSetJointTargetPosition(leftArmJoints[1],Value_minimum[5]+simGetUISlider(ui,uiSliderIDs[5])*value_range[5]/1000)
imSetJointTargetPosition(leftArmJoints[2],Value_minimum[6]+simGetUISlider(ui,uiSliderIDs[6])*value_range[6]/1000)
imSetJointTargetPosition(leftArmJoints[3],Value_minimum[7]+simGetUISlider(ui,uiSliderIDs[7])*value_range[7]/1000)
imSetJointTargetPosition(rightArmJoints[1],Value_minimum[8]+simGetUISlider(ui,uiSliderIDs[8])*value_range[8]/1000)
imSetJointTargetPosition(rightArmJoints[2],Value_minimum[9]+simGetUISlider(ui,uiSliderIDs[9])*value_range[9]/1000)
imSetJointTargetPosition(rightArmJoints[3],Value_minimum[10]+simGetUISlider(ui,uiSliderIDs[10])*value_range[10]/1000)
```

```
t=simGetSimulationTimeStep()*velocty
dist=dist+t
lPos=simGetPositionOnPath(pathlength,dist/pathlengthLength)
lOr=simGetOrientationOnPath(pathlength,dist/pathlengthLength)

p=simGetPathPosition(ppath)
rPos=simGetPositionOnPath(ppath,(dist+correction)/ppathLength)
rOr=simGetOrientationOnPath(ppath,(dist+correction)/ppathLength)


HumnaoidM=simGetObjectMatrix(Humnaoid,-1)
HumnaoidMInverse=simGetInvertedMatrix(HumnaoidM)

m=simMultiplyMatrices(HumnaoidMInverse,simBuildMatrix(lPos,lOr))
m[8]=m[8]*stepIse
m=simMultiplyMatrices(HumnaoidM,m)
lPos={m[4],m[8],m[12]}
lOr=simGetEulerAnglesFromMatrix(m)

m=simMultiplyMatrices(HumnaoidMInverse,simBuildMatrix(rPos,rOr))
m[8]=m[8]*stepIse
m=simMultiplyMatrices(HumnaoidM,m)
rPos={m[4],m[8],m[12]}
rOr=simGetEulerAnglesFromMatrix(m)


simSetObjectPosition(foot_l,-1,lPos)
simSetObjectOrientation(foot_l,-1,lOr)

simSetObjectPosition(rightt-foot,-1,rPos)
simSetObjectOrientation(rightt-foot,-1,rOr)
```

For the simulation required help has been taken from Asti robot which has helped in achieveing the desired results. Also the geometry has been taken from Poppy Beta from Flowers.

The object handles are being called from the script to retrieve its control such as shoulder joints, neck joints, ui interface etc. Define walking speed, step size and default angle of all the joints. (Fig 11 &12) Set the range of the motor along with its min & max values. Store all the data in an array for ease in control. Determine the target position of each leg and retrieve the current orientation of each joint. Increment the time and find the local position and orientation of each link. Form the object matrix and multiply the inverse with position and orientation matrix. Modify the current orientation with the new calculated orientation.

Motion Characteristics of various links & joints

Angular Position of left & right leg motors:

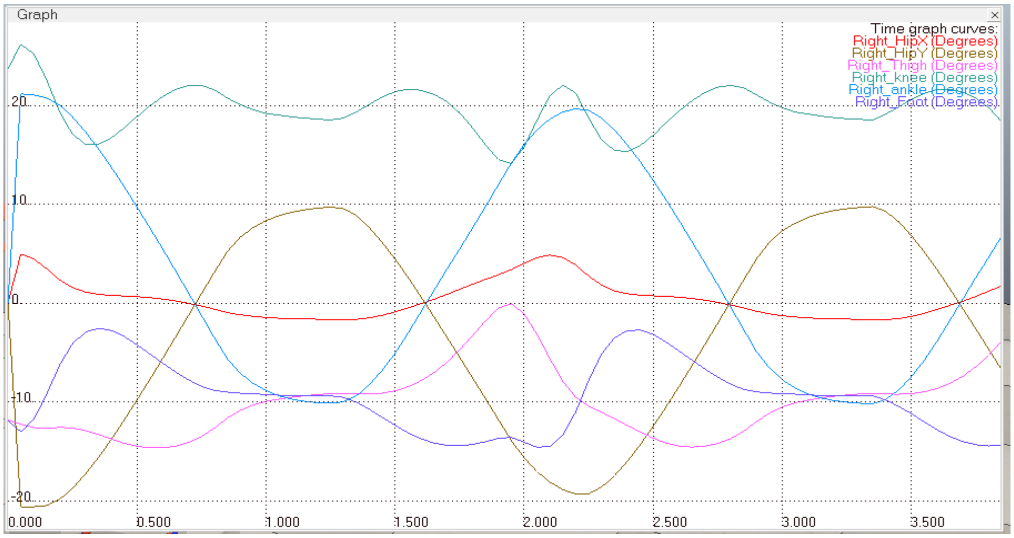



Fig 14 Angular Position of motors of Right leg

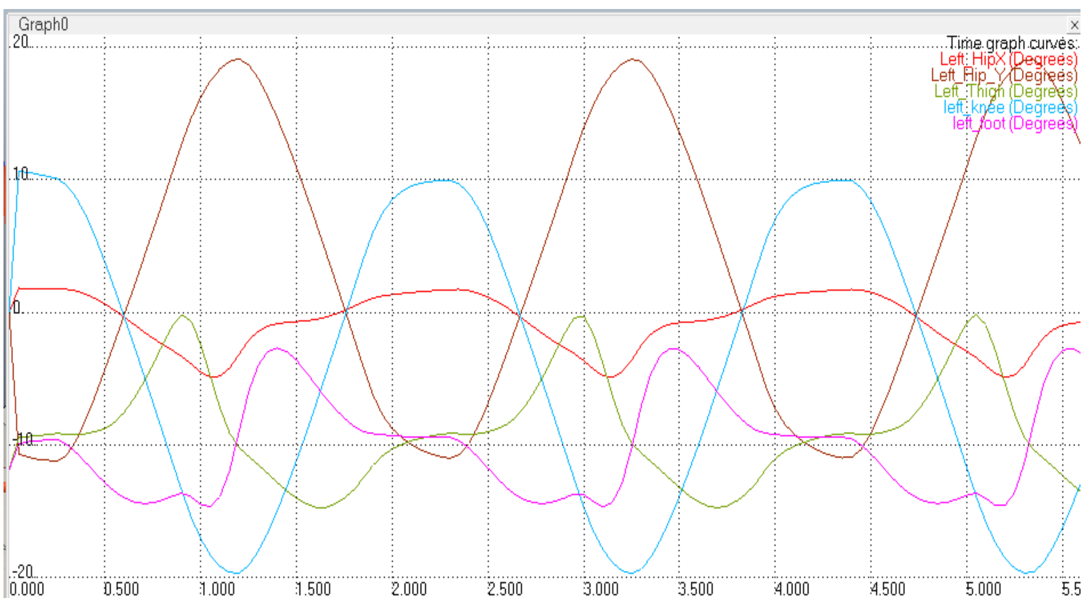



Fig 15. Angular position of motors if left leg

Angular Velocity of Right leg motors.

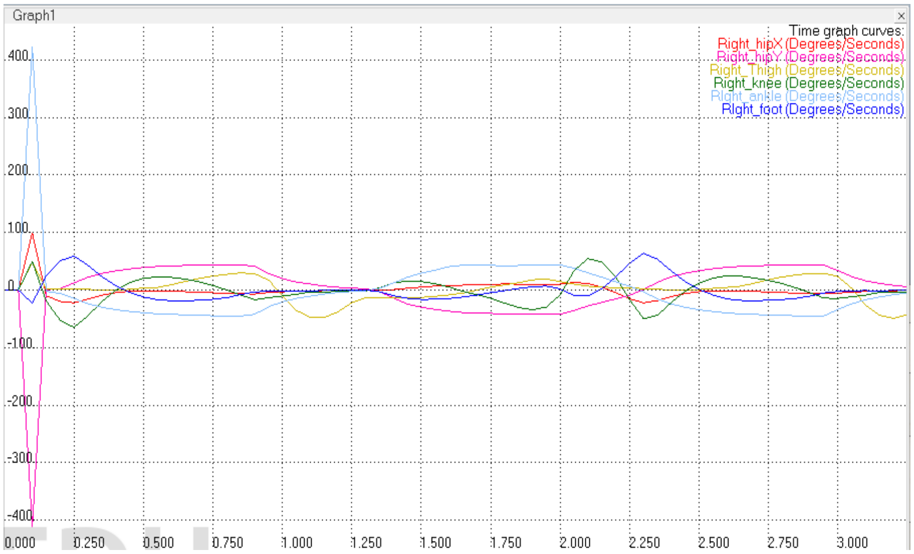



Fig 16. Angular velocity vs time graph of right leg

Torque Characteristics of Right Leg Motors

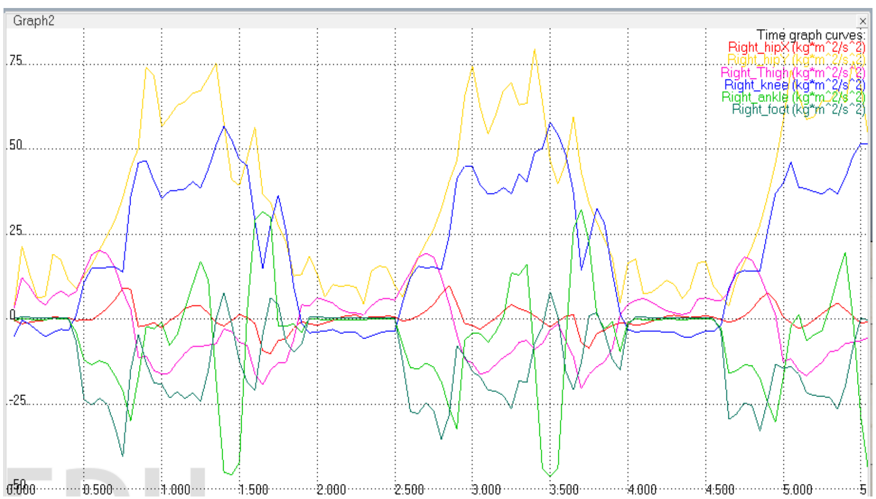



Fig 17 Torque vs Time graph of right leg

The orientation of HipX does not vary as much in linear walking but a slight more variation occurs in HipY. The thigh motors vary a lot around 30 degrees in a cyclic smooth motion. (Fig 14) Similarly the knee motors have equal movement but with a phase change of 180 degrees. The ankle and foot motors only change the orientation to form a proper contact with the ground.

# Chapter 7

# 3D Printing

**Fabrication of the robot**

Concept of 3D printer:

Printer used : Prusa I3

Table 3. Specifications of the Printer

| Sl. No | Component | Specification |
|---|---|---|
| 1. | Layer Resolution | 100 Microns |
| 2. | Print size ( X Y Z ) | 200mm x200mm x180mm |
| 3. | Chasis | Aluminium, Plexiglas or Iron |
| 4. | Printing Filament | ABS, PLA |
| 5. | Filament Diameter | 3 mm, 1.75 optional |
| 6. | Nozzle Diameter | 0.4 mm, othersizes optional |
| 7. | Machine Dimensions | 420mm x370mm x380mm |
| 8. | Machine weight | 7 kg |
| 9. | Print Speed | 50-100 mm/s recommended |
| 10. | Print Plate Size | 200mm x 200mm |
| 11. | AC Input | 110V or 220V |
| 12. | No.of Extruders | One |
| 13. | No.of Extruders | 12V 33A |
| 14. | Electronics | RAMPS 1.4 + Arduino Mega 2560 |
| 15. | 3D printing Software | Pronterface or Repetier |

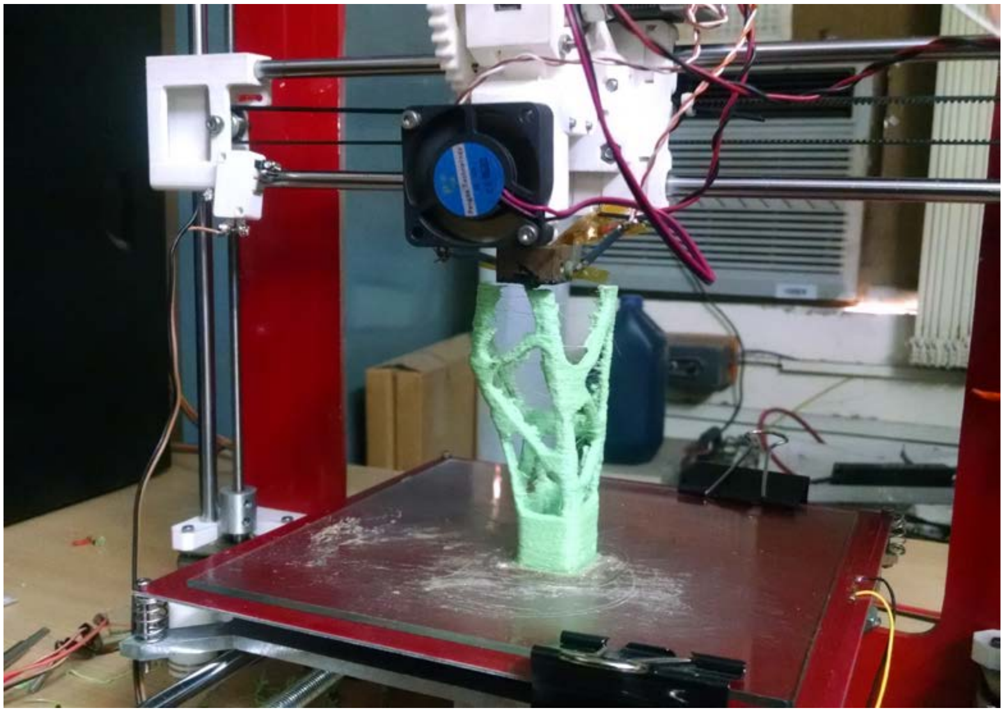


Fig 18. 3D printer fabricating the robot.

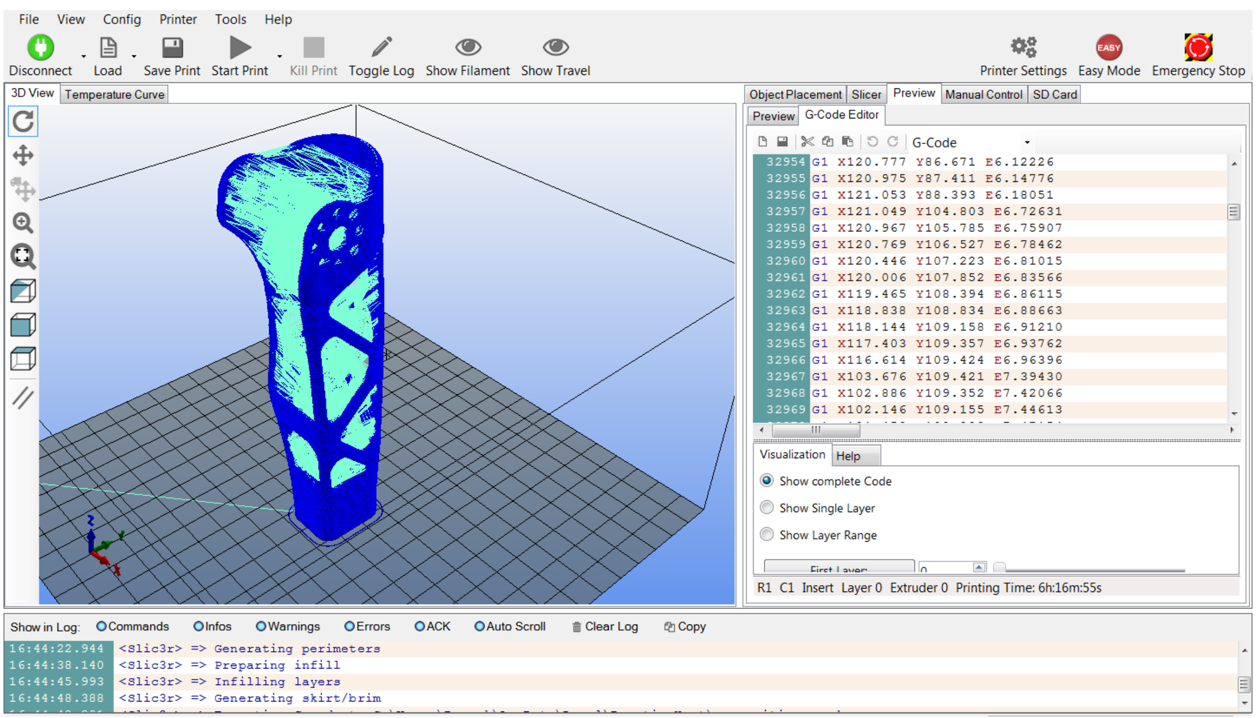



Fig 19. Reptier Host screen shot display of 3D printer.

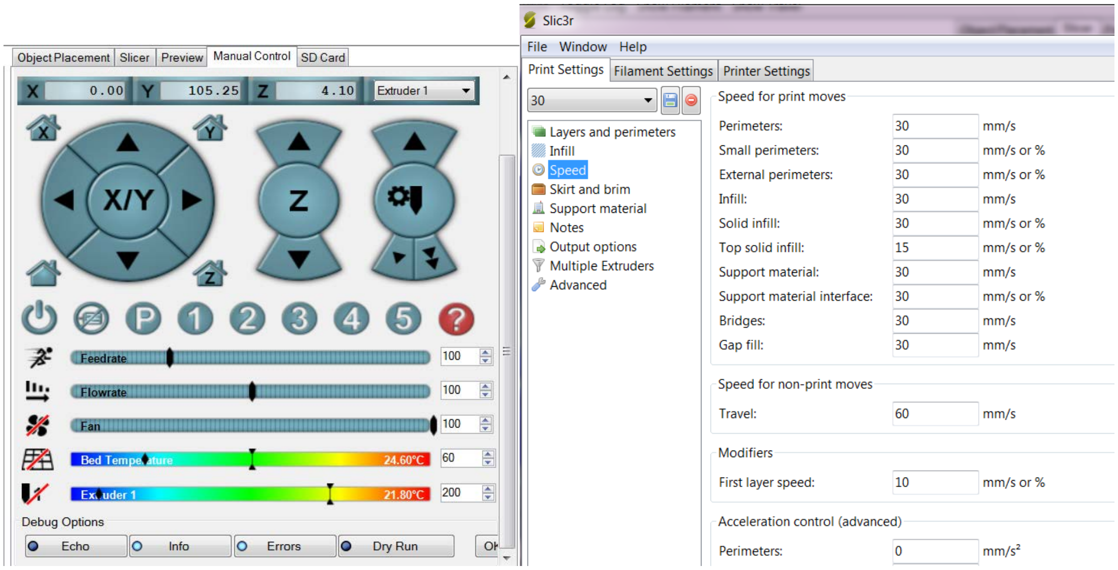



Fig 20. Control settings of the printer and the Slic3r

3D printers have grown fast in this decade due to the fact that these can make our designs come true in real life within a very short span of time. (Fig 17) These are cheap and the developed products are strong enough to deliver the desired results. Since materials like ABS, PLA are readily available this technique has reached a wide area. The current design is very suitable to be developed with this printer due to the complexity in shape and developing lighter components because of the torque issues. The accuracy and precision offered are also good along with the time needed to develop them is really low. (Fig 18) The conventional approach of fabrication is labor intensive and required a well facilitated workshop to carry out the process. If the design does not offer the desired results it can be modified easily in CAD software like Solidworks and again re-printed.  Many slicing software are available like slic3r and CuraEngine (Fig 19) which are open source and offer many features like Skirt, draft and filling techniques like linear, octa, splines, angular etc. The strength can also be modified by altering the setting of the slicer. The surface finish can be improved by acetone both which is performed to avoid interference.

# Chapter 8

# Fabrication and Result

| Sl No | Part/Link | Simulation | Prototype | % Error |
|---|---|---|---|---|
| | | Angular Position (Degrees) | | |
| 1 | Hip Left | 90 | 90.45 | 0.5 |
| | | 91 | 91.913 | 1.001 |
| | | 92 | 93.25 | 1.35 |
| | | 93 | 96.544 | 3.80 |
| | | 94 | 98.67 | 5.18 |
| 2. | Hip Right | 90 | 90.68 | 0.75 |
| | | 91 | 91.12 | 0.13 |
| | | 92 | 92.57 | 0.61 |
| | | 93 | 95.45 | 2.63 |
| | | 94 | 97.59 | 3.86 |

Table 4. Deviation between simulation & Prototype for stability for hip motors.

| Sl No | Part/Link | Simulation | Prototype | % Error |
|---|---|---|---|---|
| | | Angular Position (Degrees) | | |
| 1 | Thigh Left | 70 | 70.36 | 0.51 |
| | | 69 | 69.65 | 0.94 |
| | | 68 | 67.25 | 1.12 |
| | | 67 | 65.73 | 2.65 |
| | | 66 | 63.91 | 5.1 |
| 2. | Thigh Right | 110 | 111.02 | 0.9 |
| | | 111 | 112.25 | 1.12 |
| | | 112 | 114.37 | 2.13 |
| | | 113 | 116.08 | 2.7 |
| | | 114 | 117.27 | 2.93 |

Table 5. Error analysis for thigh motors

It can be observed for the derived and measured data that there is no much deviation from the simulated results. The hip motors are varied for 5 degrees in simulation as well as in coding. (Table 4) The robot falls in simulation but practically it can go up to 8 degrees more. This can be due to the reduced weight of the links during 3d printing where various infill techniques are used. Thus the 3d printed model in more stable than the simulated model with maximum error of 5%. Similar results can be seen varying thigh motors. (Table 5)

The printed parts have been assembled using PLA welding wherever necessary and the removable parts screwed together. The single shaft servo motors have been converted to dual shaft by developing a revolute joint out PLA.

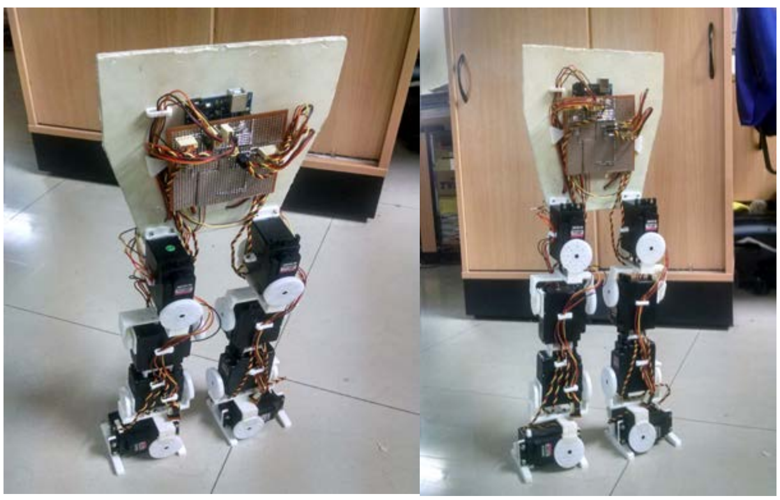


Fig 21. Pose of the robot for stability

Each leg contains four servo motors to offer 4 degrees of freedom. All motors are connected end to end to form a linear link connected to the base. Arduino mega is attached to the base where CG of the robot is found. (Fig 21) All the wires are channeled through a non interference zone to avoid the restriction of motions through 3D printer wire clips.

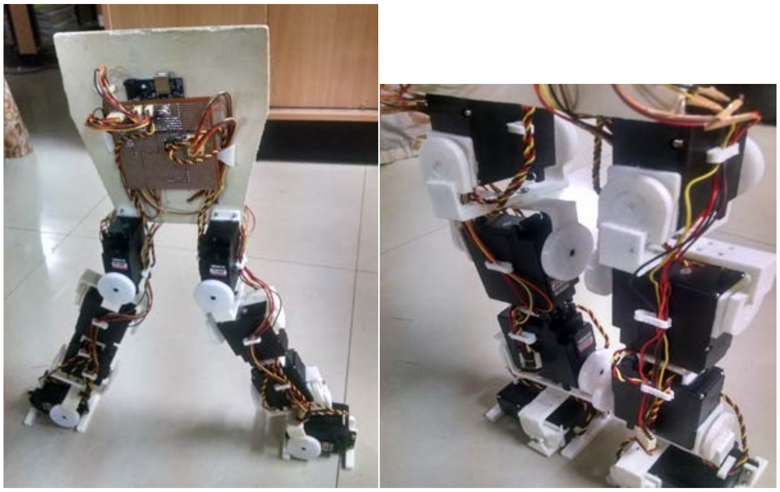


Fig 22. Rear & front view of the fabricated humanoid robot

## Conclusion:

The detailed motion study of the robot has been carried out in various software and a suitable design is developed using CAD. Finite element analysis has also been done to reduce the weight of the links which result in light body weight and ease in control of the bot. Step by step process has been adopted to carry out the project in a smooth and functional way.

3D printer technology has been adopted for fabrication of the link joints using PLA. The various links have been joined using PLA welding along with the use of epoxy resins where ever necessary. Atmega 2560 with Arduino library has been used to control the motion of the servo motors which are powered by SMPS. Still the process of developing the robot is going on. Increase of 4DOF in each to 6DOF is going on. A suitable control method using Raspberry pi will be initiated for better graphical display and user interaction.

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